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Power Quality Evaluation and Improvement of 11kv 25km Power Distribution Network

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ABSTRACT
Power quality is an essential factor for a stable power system operation. This has become a significant concern due to the increasing complexity of modern electrical networks and malfunctions of sensitive electronic devices. This work presents a comprehensive study on the evaluation and improvement of power quality on 11KV Ekwuluobia - Isuofia distribution network. The research focuses on identifying common power quality issues such as voltage sags, swell, harmonics, transient and interruptions that affect the reliability and performance of the distribution network. Various power quality evaluation techniques were studies, but D-STATCOM FACTS device was employed for the improvement of the power quality with the use of MATLAB/Simulink S-Transform model for the detection of various power quality problems. Based on the evaluation results, this research proposes effective strategy such as the use of D-STATCOM for the improvement of the power quality. The findings in this research aim to assist utilities engineers and stakeholders in enhancing power quality standard, optimizing system performance and ensuring efficient operation of the 11KV distribution network.
Keyword: *D-STATCOM, MATLAB, Simulink, Distribution, S-Transform, Transmission, Voltage, Current.*

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I. INTRODUCTION

The primary function of the electrical distribution network is to deliver electricity from the transmission system to end-users, including residential, commercial, and industrial consumers. It ensures that electrical power generated at power plants reaches users in a usable form.

Power is typically generated at high voltages for efficient long-distance transmission and then stepped down to lower voltages suitable for consumer use. The distribution network includes transformers that perform this voltage transformation, ensuring that electricity can be safely and effectively used by different types of loads.

A well-designed distribution network ensures reliable and continuous supply of electricity. It includes features like redundancy, fault tolerance, and automated control systems to minimize outages and quickly restore power in case of faults.

Distribution networks help in managing and balancing the load across different areas. By monitoring and controlling the flow of electricity, utilities can ensure that no part of the network is overloaded, which helps in maintaining system stability and preventing blackouts.

Modern distribution networks facilitate the integration of distributed energy resources (DERs), such as solar panels and wind turbines, which are often connected at the distribution level. This helps in promoting sustainable energy solutions and reducing reliance on fossil fuels (Engel, et al 2002).

Distribution networks are equipped with various devices to regulate voltage and ensure power quality. This includes maintaining voltage levels within specified limits, reducing harmonics, and minimizing power losses, which is crucial for the proper functioning of electrical equipment.

In summary, evaluating the power quality of the distribution network is essential for protecting equipment, ensuring system reliability, improving energy efficiency, achieving economic benefits, complying with regulations, enhancing customer satisfaction, integrating renewable energy sources, and guiding future planning and investments.

II. METHODOLOGY

The data needed for the evaluation and improvement of the power quality of the Ekwuluobia – Isuofia 11KV power distribution network include; the distribution electrical quantities (line voltage, current, frequency, line length etc). The material needed in this research work are MATLAB/Simulink software.

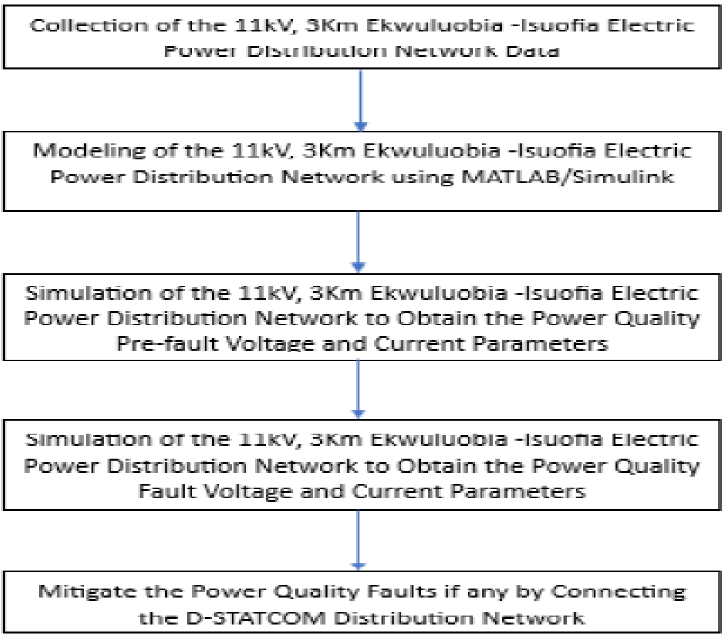


Figure 1.0: Process Flow Block Diagram

Evaluation of power quality is paramount, hence figure 1.0 describes the process of evaluation and mitigation of the power quality faults.

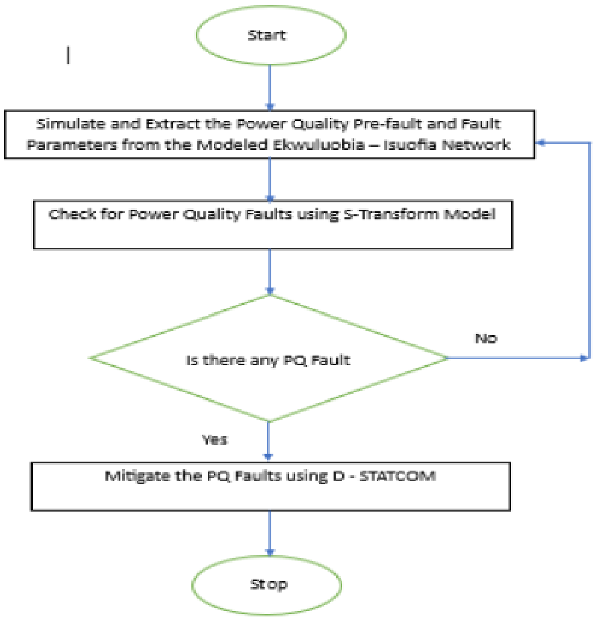


Figure 2.0: Flowchart of the Process

Figure 2.0 describes the process of evaluation and mitigation of the power quality faults using the modeled Distribution Static Compensator (D-STATCOM).

The distribution network is modeled using the MATLAB/Simulink software. The pre-fault and fault parameters of the distribution network were extracted by connecting the S-Transform model to the distribution network to check if there are power quality faults or not. The network continues its operation when there are no power quality problems. But power quality faults occur in the system due to load variations, other natural factors such as lightning etc but are mitigated using D- STATCOM.

A. Modeling of the Distribution Network

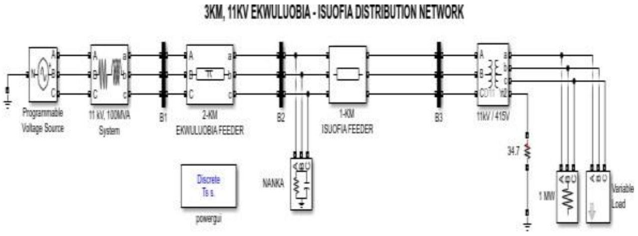


Figure 3.0: 11kV, 3Km Ekwuluobia – Isuofia Distribution Network

Table 1.0 is the distribution network parameters extracted from Ekwuluobia-Isuofia distribution network modeled using MATLAB/Simulink.

Table 1.0: Distribution Network Parameters

S/N	Parameters	Value
1	Active Power	10MW
2	Apparent Power	100MVA
3	Reactive Power	-
4	Distance	3Km
5	Voltage Source (Sending End)	11Kv
6	Voltage Source (Receiving End)	415V
7	Power Factor	0.9
8	Line Resistance	0.01632 ohms
9	Line Inductance	0.0023466 Henry
10	Line Capacitance	8.939e-9 Farad

The Ekwuluobia – Isuofia 11kV, 3Km Distribution Network is modeled on the MATLAB/Simulink using simcape power system toolbox. The network figure 3.0 consists of a programmable voltage source which supplies 11kV voltage through the network. It also feeds the entire Ekwuluobia and the Isuofia region. The network contains a variable load which when varied will yield different pre-fault and fault voltage and current magnitudes for different power quality faults shown in figures 11, 12, 15 and 16.

B. Modeling and Detection of Power Quality Faults using S-Transform

S-Transform analysis technique is a powerful tool for fault detection for protection of the power system components. It is an invertible analytical technique that comprises a combination of Short Time Fourier Transform (STFT) and Wavelet Transform (WT). The mathematical expression derived from Short Time Fourier Transform (STFT) and Wavelet Transform (WT) to solve the problem of limitations of STFT applications. S – Transform has an advantage in the sense that, it provides multi-resolution analysis while retaining the absolute phase of each frequency. This is one of reasons why it has been chosen in the field of electrical engineering for fault diagnosis in time series. The following expression is the S-Transform for a continuous voltage and current signals current x (t);

$Where, n = 0, 1 \ldots, N-1$. Also, the Fourier spectrum of the Gaussian window at a specific n (frequency) is called a voice Gaussian and for the frequency, $f_1(n_1)$, the voice can be obtained as:

$$S(j, n_1) = A(j, n_1).\, e^{(j\Phi(j,n_1))} \quad (4)$$

Where the pick value of the voice is:

$$\max(S(j, n_1)) = \max(A(j, n_1)) \quad (5)$$

And

$$\Phi(j, n_1) = \operatorname{atan}\left\{\frac{\operatorname{imag}(S(j,n_1))}{\operatorname{real}(S(j,n_1))}\right\} \quad (6)$$

Then, the energy E of the signal is obtained from S – Transform as

$$E = \{\operatorname{abs}(S(j, n_1))\}^2 \quad (7)$$

The energy signal obtained from S - Transform is used to detect and classify the fault on the transmission line.

$$S(\tau, f) = \int_{-\infty}^{\infty} x(t) \left\{\frac{|f|}{\alpha\sqrt{2\pi}}\right\} . e^{\left(\frac{-f^2(\tau-t)^2}{2\alpha^2}\right)} . e^{(-2\pi ift)} dt \quad (1)$$

Where f is the frequency, t is the time, τ is the parameter that controls the position of Gaussian window on the t-axis and α is a control factor of time and frequency resolution of the transform. The lower α means higher time resolution and lower frequency and vice versa. A suitable value of α lies between the ranges of $0.2 \le \alpha \le 1$. Considering the discrete version of the continuous discrete S-Transform (DST), the following expression describes the DST.

$$S(j, n) = \sum_{m=0}^{N-1} X(m+n). e^{\left(\frac{-2\pi^2 m^2 \alpha^2}{n^2}\right)} . e^{(i2\pi mj)} \quad (2)$$

$Where, j = 1, \dots N-1;\ n = 0, 1 \dots N-1.$

But j and n indicate the time samples and frequency step respectively.

X (m + n) can be obtained in a straight forward manner from equation 3.9 below.

$$X(n) = \frac{1}{N} \sum_{K=0}^{N-1} x(k) . e^{(i2\pi nk)} \quad (3)$$

Figure 4.0: S-Transform Model for Voltage Magnitude

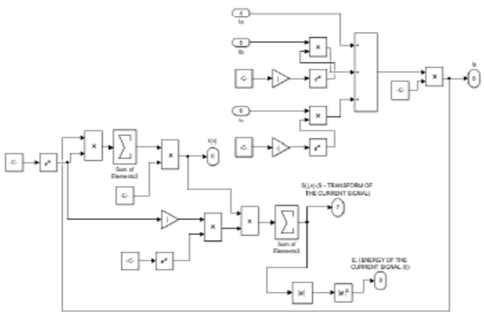


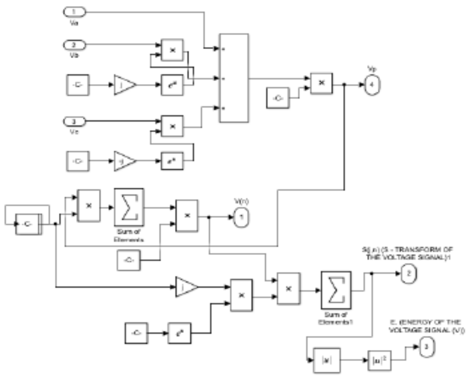
Figure 5.0: S-Transform Model for Current Magnitude

Figure 4.0 and 5.0 are S-Transform model diagrams for detection of pre-fault and fault voltage and current magnitude respectively. The diagram consists of Simulink mathematical blocks which represents the variables of the equations (2), (3) and (7). When the model connected to the distribution line and simulated, it detects the voltage and current magnitude for a given condition.

C. Mitigation of the Power Quality Faults using D-STATCOM

The D-STATCOM is built using simpowersystem toolbox in MATLAB/Simulink environment. We need to consider a more severe power quality faults, these include; Voltage sag, Voltage swell, Voltage Flicker, Harmonics, Over voltage, Under voltage and Transients.

From the above analysis it is quite evident that not only S-Transform localizes the faulted event but also peak amplitude and phase information of the voltage and current signals can be obtained, which are required for impedance trajectory calculations. The signal energy obtained from S-Transform can be used to detect and classify the fault on the transmission line. The following Figures 4.0 and 5.0 are internal MATLAB/Simulink diagram S-Transform of the voltage and current signals. When the figures are simulated, they show a waveform diagram of voltage and current magnitudes for pre-fault and fault conditions.



The D-STATCOM is a three-phase and shunt connected power electronics-based device. It is connected near the load at the distribution systems. The major components of a D-STATCOM are shown in Figure 6.0.

The function of D-STATCOM is to regulate the bus voltage by absorbing or generating reactive power to the network like a Thyristor Static Compensator. This reactive power transfer is done through the leakage reactance of the coupling transformer by using a secondary voltage in phase with the primary voltage.

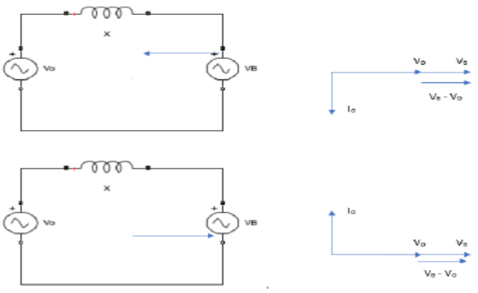


Figure 7.0: D-STATCOM operation

This voltage is provided by a voltage source PWM inverter. The D-STATCOM operation is illustrated by the phasor diagrams shown in Figure 7.0. When the secondary voltage (V_o) is lower than the bus voltage (V_b), the D-STATCOM acts like an inductance absorbing reactive power from the bus. When the secondary voltage (V_o) is higher than the bus voltage

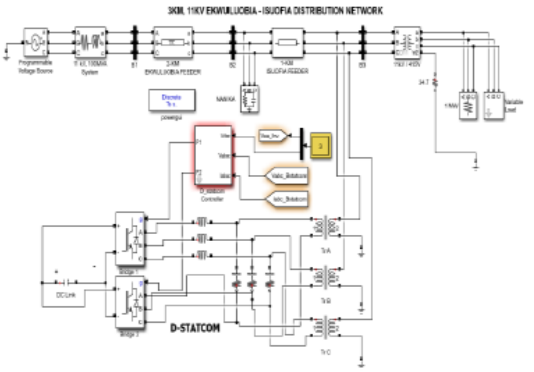


Figure 6.0: The D-STATCOM

and control systems in the MATLAB/Simulink environment. Modelling the

D-STATCOM including the power network and its controller in Simulink environment requires electric blocks from power system block set and control blocks from Simulink library.

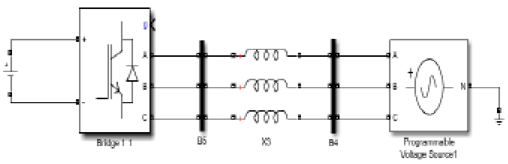


Figure 8: Equivalent One-Line Circuit Diagram of D-STATCOM

Figure 8 is the equivalent one-line circuit diagram of D-STATCOM. It shows the simplified one-line equivalent circuit of the D-STATCOM, including a DC side capacitor, an IGBT inverter and series resistance and inductance. The inverter is connected to capacitor C which supplies the DC voltage. The resistance R accounts for the sum of the transform winding resistance loss and the inverter conduction losses. The inductance L accounts for leakage inductance of transformer. The three-phase system voltage is given by equations (1).

$$\begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot V_s \cdot \begin{bmatrix} cosw_0 t \\ cosw_0 t - \frac{2}{3}\pi \\ cosw_0 t + \frac{2}{3}\pi \end{bmatrix} \tag{8}$$

where Vs is the rms value of the AC system line-line voltage. When the fundamental positive component is used as the synchronizing signal, the output voltage of the inverter is expressed as follows

$$\begin{bmatrix} V_{ia} \\ V_{ib} \\ V_{ic} \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot kV_{dc} \cdot \begin{bmatrix} cosw_0 t + \delta \\ cosw_0 t + \delta - \frac{2}{3}\pi \\ cosw_0 t + \delta + \frac{2}{3}\pi \end{bmatrix} \tag{9}$$

(V_b), the D-STATCOM acts like a capacitor supplying reactive power to the bus. In steady state, due to inverter losses, the bus voltage always leads the inverter voltage by a small angle to supply a small active power.

The D-STATCOM is built using a digital simulation model of the D-STATCOM connected to a three-phase source along with a normal household load and a heavy load is developed. using the MATLAB/Simulink power system block set (PSB). The PSB is a graphical tool that allows for building schematics and simulations of Power Systems. It unifies power network, power electronics operation can be expressed in terms of instantaneous variable.

$$\frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} -\frac{R}{L} & 0 & 0 \\ 0 & -\frac{R}{L} & 0 \\ 0 & 0 & -\frac{R}{L} \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{1}{L}\begin{bmatrix} V_{sa} & - & V_{ia} \\ V_{sb} & - & V_{ib} \\ V_{sc} & - & V_{ic} \end{bmatrix} \tag{10}$$

The D-STATCOM model can be described in the state space by the dq component as follows

$$\frac{d}{dt}\begin{bmatrix} i_d \\ i_q \\ i_{dc} \end{bmatrix} = A\begin{bmatrix} i_d \\ i_q \\ V_{dc} \end{bmatrix} + \frac{1}{L}\begin{bmatrix} V_s \\ 0 \\ 0 \end{bmatrix} \tag{11}$$

Where;

$$A = \begin{bmatrix} -\frac{R}{L} & w_0 & -\frac{k}{L}cos\delta \\ -w_0 & -\frac{R}{L} & -\frac{k}{L}cos\delta \\ \frac{k}{L}cos\delta & \frac{k}{L}cos\delta & 0 \end{bmatrix} \tag{12}$$

Using the definition of reactive power theory and considering that $V_q = 0$, the real power(p) and the reactive power (q) injected into the system by the D-STATCOM can be expressed under the d_q reference frame as;

$$p = v_d i_d + v_q i_q = v_d i_d \tag{13}$$

$$q = v_q i_d - v_d i_q = -v_d i_q \tag{14}$$

It can be seen that i_d and i_q can completely describe the instantaneous values of the real and reactive powers produced by the D-STATCOM when the system voltage remains constant. Therefore, the control of the power injected into the system can be implemented by controlling i_d and i_q. The steady state operation can be obtained from equation (15) and expressed as follow

$$\delta = \delta_0 \tag{15}$$

Where;

VDC is the inverter DC-side voltage, k is the ratio of the inverter output line-line voltage to the DC-side voltage and δ is the phase angle by which the D-STATCOM equipment leads the system voltage. The AC-side circuit The characteristic equation of the D-STATCOM model is expressed as;

$$S^3 + \frac{2R}{L}S^2 + \left(\frac{R^2}{L^2} + \frac{k^2}{LC} + w_0^2\right)s + \frac{RK^2}{L^2C} = 0 \qquad (19)$$

Here in the design,

R = 0.01ohms

L=2mH

C = 2.2Mf

Note that equation (15) is independent of the control angle. It has three roots: a real eigen value and a pair of complex eigen values. All the roots have negative real parts, which means that the DSTATCOM is a damped and stable system.

During this test, the variable load will be kept constant and you will observe the dynamic response of a D-STATCOM to step changes in source voltage. Check that the modulation of the Variable Load is not in service (Modulation Timing [Ton Toff] = [0.15 1] * 100 > Simulation Stop time). The Programmable Voltage Source block is used to modulate the internal voltage of the 11-kV equivalent.

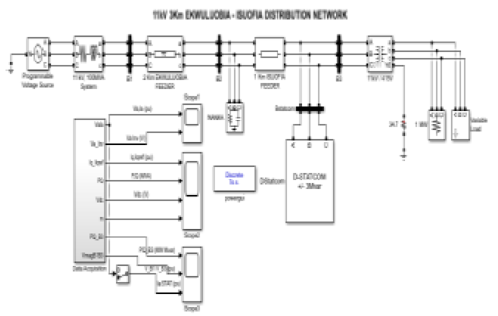


Figure 9: MATLAB/Simulink diagram of 11KV Ekwuluobia – Isuofia Distribution Line with D-STATCOM

$$i_{d0} = \frac{V_s sin^2 2\delta_0}{R} \qquad (16)$$

$$i_{q0} = \frac{V_s sin^2 2\delta_0}{2R} \qquad (17)$$

$$V_{dc0} = \frac{V_s}{k}\left[cos\delta_0 - \frac{w_0 L}{R} sin\delta_0\right] \qquad (18)$$

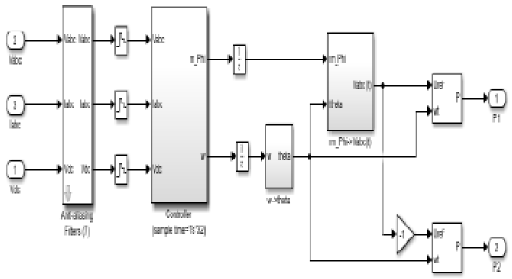


Figure 10: Control System of the D-STATCOM

III. RESULTS AND DISCUSSION

A. Simulation Results using D-STATCOM

D-STATCOM method for mitigating the power quality problems is implemented by keeping every other parameter constant except load, reactive power, fault voltage and current. The fault voltage and current vary due to variation of the load.

There are many techniques to mitigate the power quality problems. Among them the best way is to use a device at the point of interest to regulate the voltage. The devices used for this purpose are already discussed along with their control techniques in the previous chapters. These control strategies are simulated in MATLAB SIMULINK. This chapter presents the simulation results of the devices based on its performance. Power quality problems are created for simulation with D-STATCOM by connecting an extra load in the circuit. The resultant changes in the voltage are shown in the figures below.

The control circuit of the D-STATCOM gets activated. As it is a shunt connected device, it generates compensating current which is injected into the system. Based on the magnitude of this compensation current reactive power exchange takes place between the D-STATCOM and the distribution line. Based on this, the load bus voltage is regulated. The waveform of the compensation current is given as Ia D-STATCOM Waveform at various load changes and are shown in Fig. (11) to (20).

The waveform shows that the compensation current is not balanced. This affects the voltage and increases its harmonic content and other power quality problems. But as the load is increased, the power quality problems are cleared and improved.

B. Simulation Results using D-STATCOM at 5MW Load

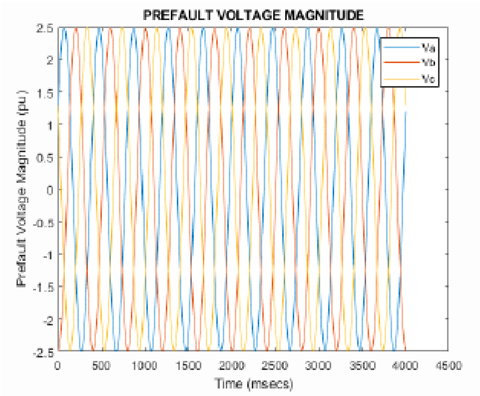


Figure 11: Pre-fault Voltage Magnitude of the Ekwuluobia-Isuofia 11kV 3Km Distribution Line

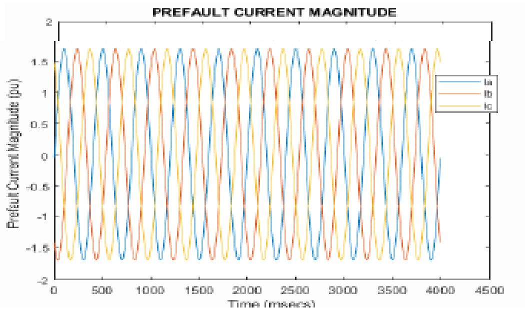


Figure 12: Pre-fault Current Magnitude of the Ekwuluobia-Isuofia 11kV 3Km Distribution Line

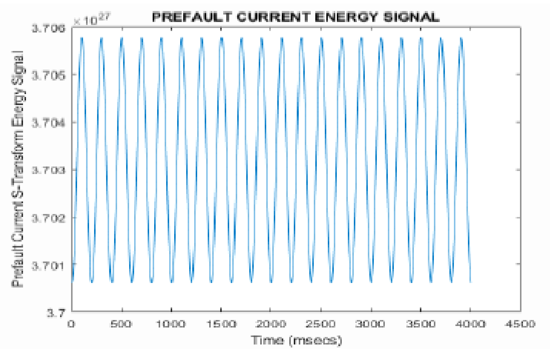


Figure 13: S-Transform Energy Magnitude of the Pre-fault Current of the Ekwuluobia-Isuofia 11kV 3Km Distribution Line

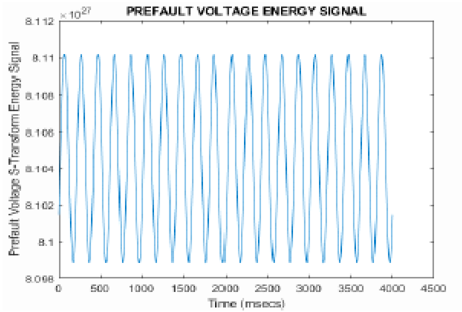


Figure 14: S-Transform Energy Magnitude of the Pre-fault Voltage of the Ekwuluobia-Isuofia 11kV 3Km Distribution Line

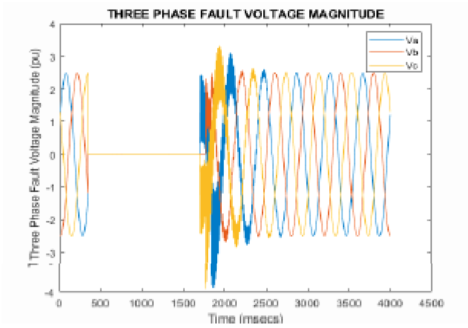


Figure 15: S-Transform Energy Magnitude of the Pre-fault Voltage of the Ekwuluobia-Isuofia 11kV 3Km Distribution Line

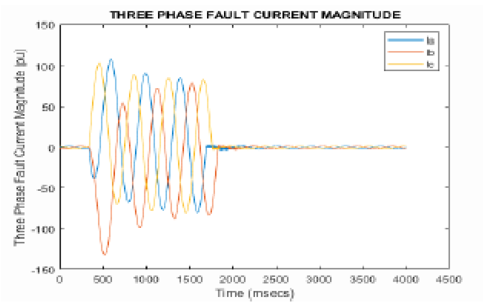


Figure 16: S-Transform Energy Magnitude of the Pre-fault Voltage of the Ekwuluobia-Isuofia 11kV 3Km Distribution Line

Figure 4.6 show that voltage sag and swell occurred when three phase fault is simulated on the distribution line and is mitigated using D-STATCOM as shown in figure 4.26, 4.31 and 4.36.

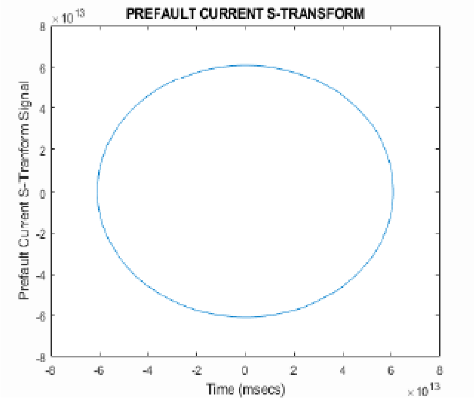


Figure 17: S-Transform Magnitude of the Pre-fault Current of the Ekwuluobia-Isuofia 11kV 3Km Distribution Line

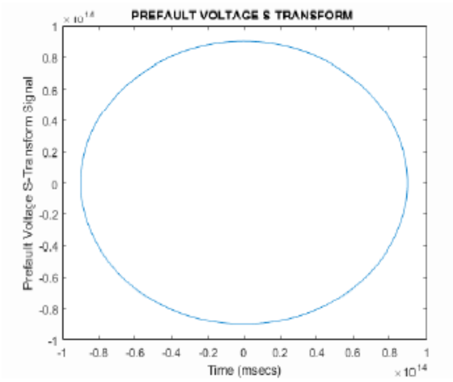


Figure 18: S-Transform Magnitude of the Pre-fault Voltage of the Ekwuluobia-Isuofia 11kV 3Km Distribution Line

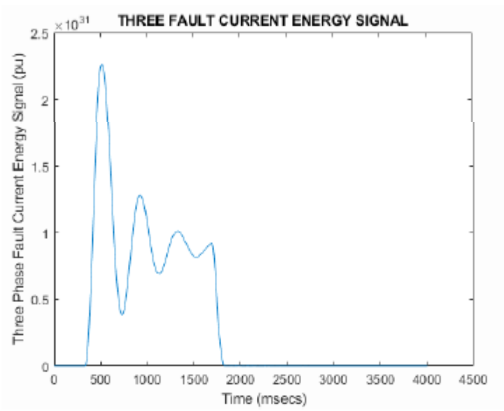


Figure 19: S-Transform Energy Magnitude of the Three Phase fault Current of the Ekwuluobia-Isuofia 11kV 3Km Distribution Line

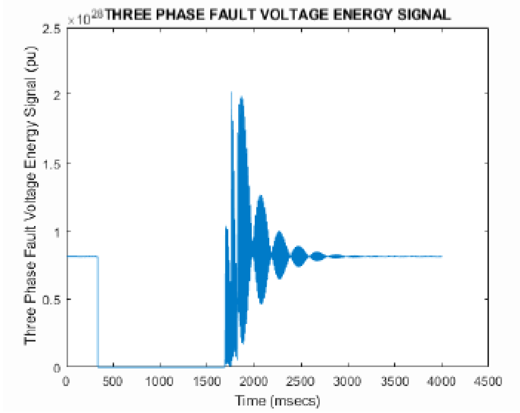


Figure 20: S-Transform Energy Magnitude of the Three Phase fault Voltage of the Ekwuluobia-Isuofia 11kV 3Km Distribution Line

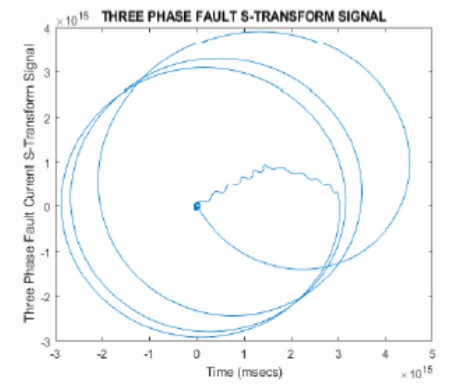


Figure 20: S-Transform Magnitude of the Three Phase fault Current of the Ekwuluobia-Isuofia 11kV 3Km Distribution Line

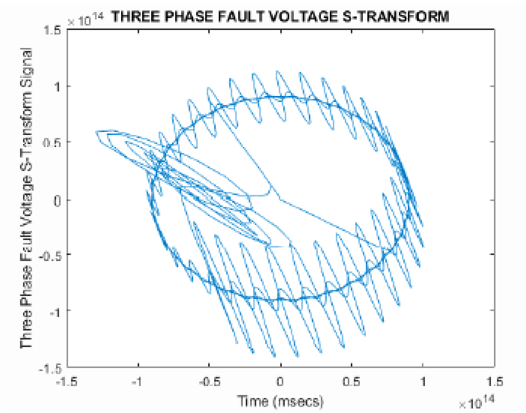


Figure 21: S-Transform Magnitude of the Three Phase fault Voltage of the Ekwuluobia-Isuofia 11kV 3Km Distribution Line

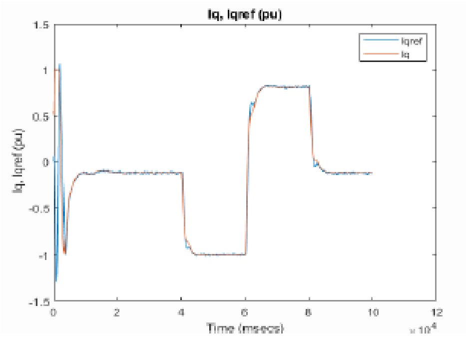


Figure 22: D-STATCOM q-axis current

In the context of D-STATCOM operation, the Iq-axis current Iq refers to the component of the current that is in quadrature (90 degrees phase shift) with the grid voltage. This component is responsible for generating or absorbing reactive power.

The q-axis current controls the reactive power exchange between the D-STATCOM and the grid. When the D-STATCOM injects a q-axis current, it can either supply or absorb reactive power depending on the conditions.

In terms of voltage regulation, by adjusting the q-axis current, the D-STATCOM regulates the voltage magnitude at the point of connection. This helps in maintaining stability of the voltage level and improving the power quality.

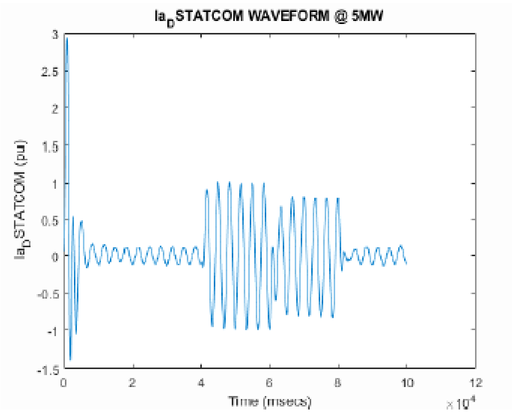


Figure 12: D-STATCOM Current to Respond to the Change in

Voltage at Bus B3 and 5MW Load

The D-STATCOM current responds to changes in voltage at Bus B3 due to a 5MW load by dynamically adjusting its q-axis current to inject the necessary reactive power, thereby stabilizing the voltage and maintaining power quality. The rapid response and precise control of the D-STATCOM make it an effective tool for voltage regulation in distribution networks.

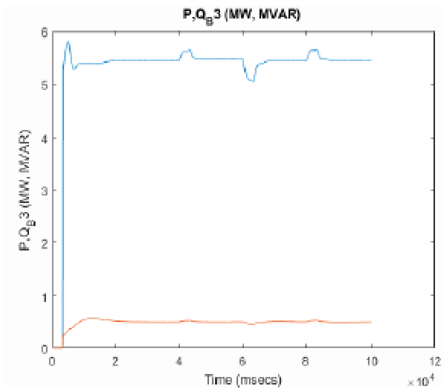


Figure 13: Real and Reactive Power, Bus B3

To understand the effects of a 5MW load on the distribution line and how a D-STATCOM at Bus B3 responds in terms of real (P) and reactive power (Q), we need to analyse the following:

While in terms of the reactive power (Q) adjustment, the D-STATCOM injects reactive power of about 5MVar to compensate for the voltage drop. The amount of reactive power required depends on the voltage drop and the line impedance.

Also, in terms of real power (P), the primary role of the D-STATCOM is reactive power compensation, it can also exchange a small amount of real power of about 0.6MW with the grid if it has an energy storage component or if it is designed to handle real power flow. However, in most cases, the D-STATCOM primarily manages reactive power.

However, the 5MW load causes a voltage drop in the distribution line, which the D-STATCOM compensates by injecting approximately 5MVAr of reactive power, thereby maintaining voltage stability at Bus B3.

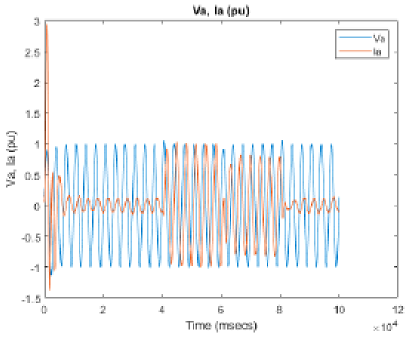


Figure 15: D-STATCOM Voltage and Current After Compensation

Notice that, voltage magnitude fluctuates in other words, the voltage flickers occurred but was mitigated using the D-STATCOM. The D-STATCOM plays a crucial role in mitigating the effects of load variations on the voltage and current in a distribution network. By dynamically adjusting its reactive power output, it stabilizes the voltage at the load bus, improves power quality, and enhances the overall efficiency of the power system.

Load variations in a distribution network can significantly impact voltage and current levels. A D-STATCOM (Distribution Static Synchronous Compensator) helps mitigate these effects by dynamically adjusting its output to maintain voltage stability and improve power quality. Let's explore how load variations affect voltage and current, and how a D-STATCOM responds to these changes:

Without the D-STATCOM, when the load increases, the voltage at the load bus tends to drop due to increased current flow through the impedance of the distribution line, but the current drawn from the source increases as the load increases.

Also, increased load leads to higher I^2R losses in the distribution line, further contributing to voltage drop and inefficiency.

However, considering figures 4.4, 4.9, 4.14, 4.18 and 4.23 with respect to load, when the load decreases, the voltage at the load bus tends to rise due to decreased current flow and reduced voltage drop across the line impedance. The current drawn from the source decreases as the load decreases. Reduction of the load leads to lower I^2R losses, which can slightly improve efficiency.

In terms of voltage stabilization, by adjusting the reactive power, the D-STATCOM keeps the voltage at the load bus stable, preventing voltage sags during high load and voltage swells during low load conditions.

In terms of power factor improvement, the D-STATCOM helps improve the power factor by providing the necessary reactive power locally, reducing the reactive power flow from the source and thereby reducing losses.

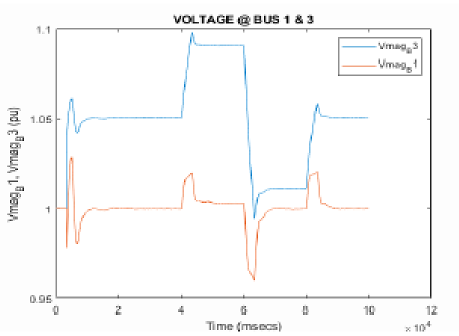


Figure 16: Voltage Change at Bus 1and B3 Due Load Variation

The dynamic response of the D-STATCOM ensures that voltage levels are maintained within acceptable limits, enhancing the stability and reliability of the distribution network. This capability is crucial for preventing voltage sags and swells, improving power quality, and reducing the risk of voltage instability due to load variations.

With increase in load when a D-STATCOM is connected to the distribution line, it helps mitigate the effects of load variations on voltage levels at different buses in the network. To understand the voltage changes at Bus 1 and Bus B3 due to load variations with the D-STATCOM in place, we can consider a detailed analysis.

Without D-STATCOM, the voltage at Bus B3 would drop significantly from its nominal value. This can be seen in figure 4.5, 4.10, 4.14. 4.19 and 4.24. But with the D-STATCOM active, the voltage at Bus 1 remains relatively stable as the D-STATCOM provides the necessary reactive power locally, minimizing the reactive power drawn from the source.

With decrease in Load, without D-STATCOM, the voltage at Bus B3 would rise slightly above its nominal value. But with the D-STATCOM active, the voltage at Bus 1 remains stable as the D-STATCOM absorbs the excess reactive power locally, preventing voltage rise at the source.

The D-STATCOM effectively maintains the voltage at Bus B3 close to its nominal value (11kV) by injecting or absorbing reactive power in response to load variations. During a load increase to 10MW, the D-STATCOM injects reactive power (5.67 MVAR) to counteract the voltage drop. During a load decrease to 2MW, the D-STATCOM absorbs reactive power (1.13 MVAR) to counteract the voltage rise.

The voltage at Bus 1 remains relatively stable because the D-STATCOM provides or absorbs the necessary reactive power locally at Bus B3, reducing the impact of load variations on the source bus.

C. Simulation Results using D-STATCOM at 10MW Load

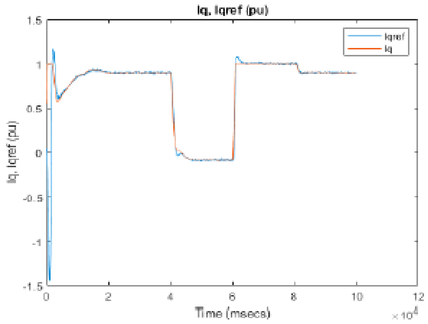


Figure 17: D-STATCOM q-axis current

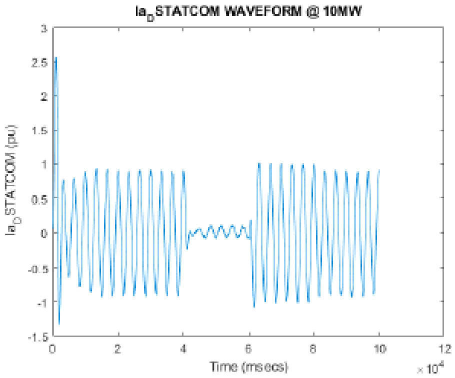


Figure 18: D-STATCOM Current to Respond the Change
in Voltage at Bus B3 and 10MW Load

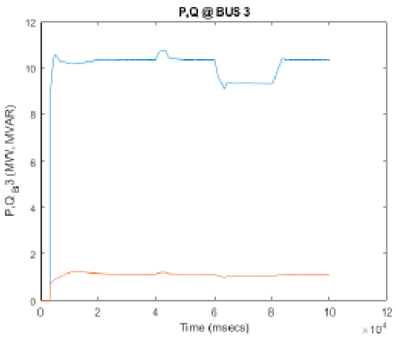


Figure 19: Real and Reactive Power, Bus B3

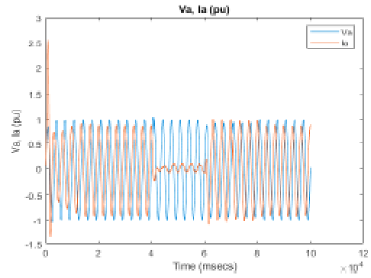


Figure 20: D-STATCOM Voltage and Current After Compensation

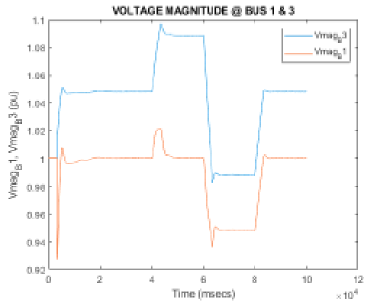


Figure 21: Voltage Change at Bus 1and B3 Due Load Variation

In terms of voltage regulation, the primary function of the D-STATCOM is to regulate the voltage at Bus B3. When the load is connected. The D-STATCOM detects the voltage drop and responds by adjusting its reactive power output. This can be seen in the figure 4.10.

When a 10 MW load variation occurs, the D-STATCOM plays a critical role in maintaining the stability and quality of the power system. By adjusting the q-axis current and voltage, the D-STATCOM ensures that the increased reactive power demand is met, and the voltage level is kept within acceptable limits, thus enhancing the overall performance of the distribution network.

D. Simulation Results using D-STATCOM at 15MW Load

With D-STATCOM, the D-STATCOM compensates for the voltage drop by injecting reactive power (Q), thus maintaining the voltage at the load bus close to its nominal value. The D-STATCOM provides reactive current support, reducing the reactive component of the current drawn from the source. This can be seen in the waveforms of figures 4.7, 4.12, 4.16, 4.21 when the load is varied.

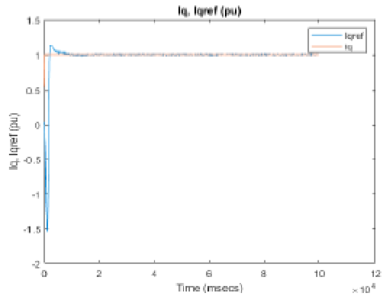


Figure 22: D-STATCOM q-axis current

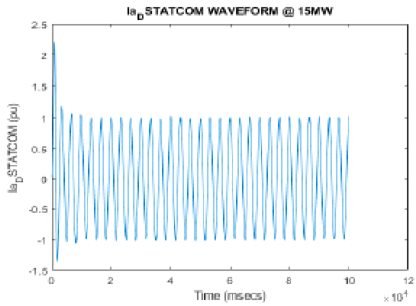


Figure 23: D-STATCOM Current to Respond the Change in Voltage at Bus B3 and 15MW Load

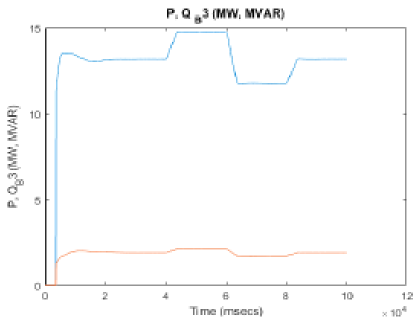


Figure 24: Real and Reactive Power, Bus B3

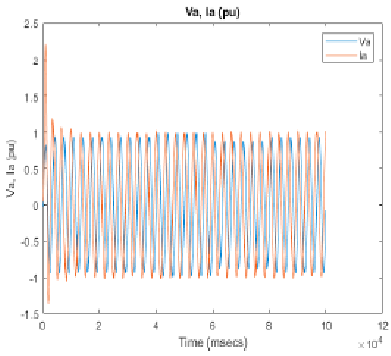


Figure 25: D-STATCOM Voltage and Current After Compensation

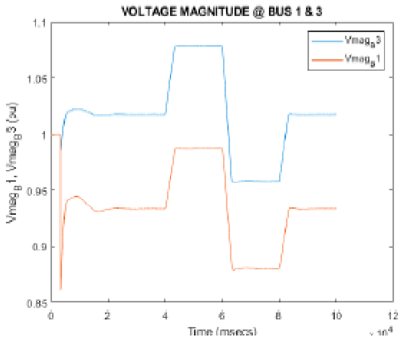


Figure 26: Voltage Change at Bus 1and B3 Due Load Variation

E. Simulation Results using D-STATCOM at 20MW Load

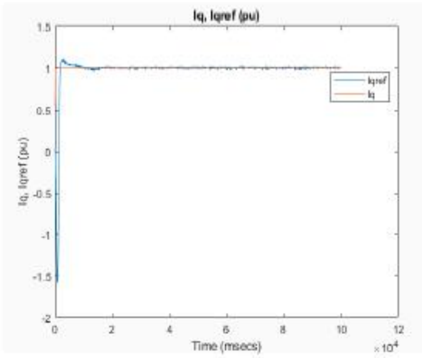


Figure 27: D-STATCOM q-axis current

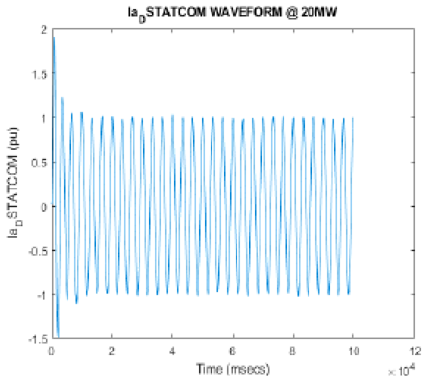


Figure 28: D-STATCOM Current to Respond the Change in

Voltage at Bus B3 and 20MW Load

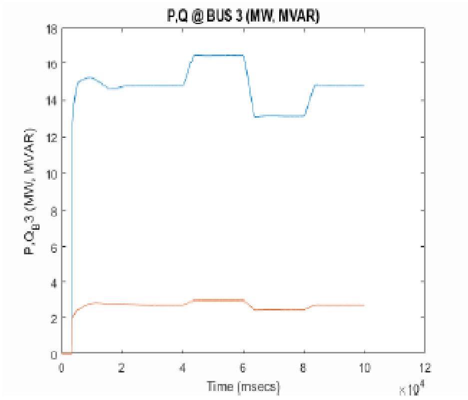


Figure 29: Real and Reactive Power, Bus B3

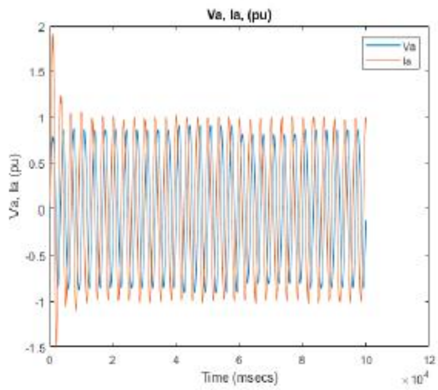


Figure 30: D-STATCOM Voltage and Current After Compensation

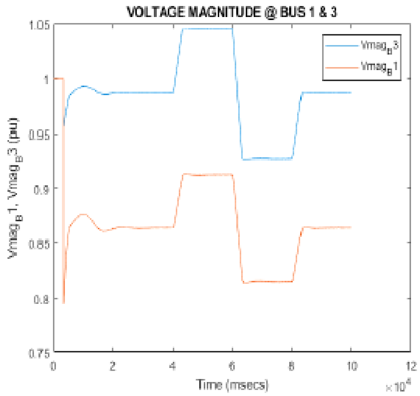


Figure 31: Voltage Change at Bus 1and B3 Due Load Variation

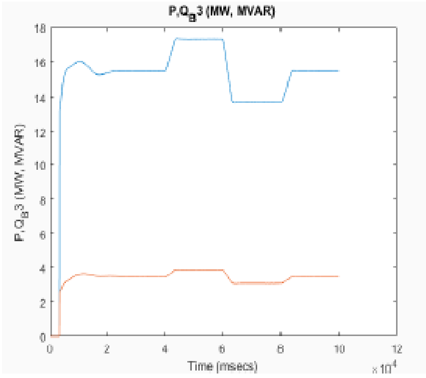


Figure 34: Real and Reactive Power, Bus B3

F. Simulation Results using D-STATCOM at 25MW Load

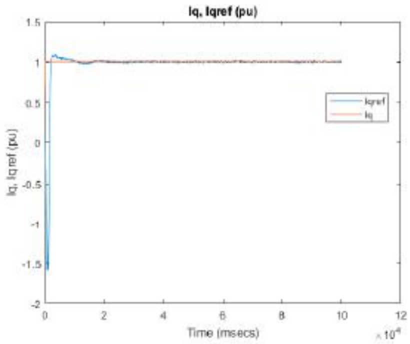


Figure 32: D-STATCOM q-axis current

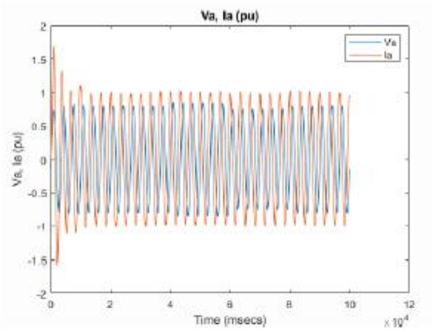


Figure 35. D-STATCOM Voltage and Current After Compensation

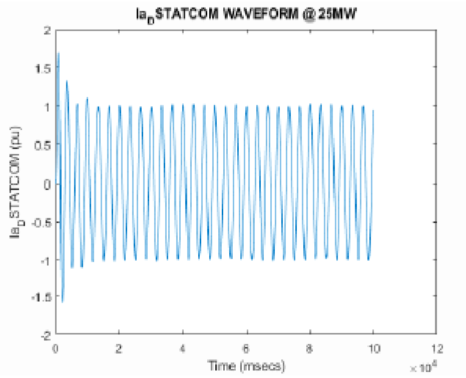


Figure 33: D-STATCOM Current to Respond the Change in Voltage at Bus B3 and 25MW Load

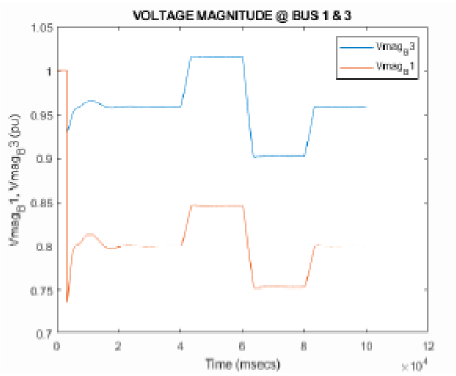


Figure 36: Voltage Change at Bus 1and B3 Due Load Variation

Table 2: Three -Phase Parameters of Ekwuluobia – Isuofia 11kV, 3Km Distribution Network

S/N	Va (pu)	Vb(pu)	Vc (pu)	Ia (pu)	Ib (pu)	Ica (pu)	Condition
1	2.5	2.5	2.5	1.6	1.6	1.6	No Fault
2	0.0	0.0	0.0	100.2	50.0	100.0	A-B-C-G

Table 3: Three -Phase Pre-fault and Fault S-Transform Signal Parameters of Ekwuluobia – Isuofia 11kV, 3Km Distribution Network

S/N	S-Tv (pu)	S-Tv (pu)	Ev (pu)	Ei (pu)	Condition
1	0.9e14	6.0e13	8.11e27	3.7e14	No Fault
2	1.5e14	4.0e15	0.8e28	2.25e31	A-B-C-G

Table 4: Result Analysis of the D-STATCOM Application
for Mitigation of Power Quality Problems on the Ekwuluobia – Isuofia 11kV, 3Km Distribution Network

S/N	LOAD (MW)	Iq (pu)	Iqref (pu)	P @ Bus 3 (MVA)	Q @ Bus 3 (MVAR)
1	5	1.0	1.0	0.5	5.7
2	10	1.0	1.0	1.0	10.0
3	15	1.0	1.0	2.0	15.0
4	20	1.0	1.0	3.0	16.0
5	25	1.0	1.0	4.0	17.0

From tables 1, illustrates the distribution network conditions and its parameters. It can be seen from the table that, when the network is simulated without fault, S-Transform voltage magnitude was larger than current counterpart. But, when three phase fault was simulated, the S-Transform was able to detect the fault and gave results that show that, the voltage magnitude dropped to 0.0pu while the current increased to above 100.2 pu, 50pu and 100pu for the three phases. Figure 4.2 show that, the S-Transform and its Energy Signal of pre-fault voltage and current are lesser that of three-phase fault. This was because of the presents of fault on the line detected by the S-Transform MATLAB/Simulink model in chapter three. Figure 4.3 show drastic increase in reactive power as the load increases. This due to compensation of D-STATCOM on the distribution line by injecting reactive power into the system to compensate for voltage drop due to power quality problems.

III. Conclusion

The demand for electric power is increasing at an exponential rate and at the same time the quality of power delivered became the most prominent issue in the power sector. Thus, to maintain the quality of power the problems affecting the power quality should be treated efficiently. Among the different power quality problems, voltage sag is one of the major one affecting the performance of the end user appliances. In this project the methods to mitigate the voltage sag are presented. From this project, the following conclusions are made;

Among the different methods to mitigate the power quality problems, the use of FACT devices is the best method. The D-STATCOM is helpful in overcoming the voltage unbalance problems in power system. D-STATCOM is a shunt connected device and injects current into the system. Its devices are connected to the power network at the point of interest to protect the critical loads. It has other advantages like harmonic reduction, power factor correction.

The D-STATCOM require a greater number of power electronic switches and storage devices for their operation. To overcome this problem, PWM switched auto-transformer is used for mitigating the voltage sag.

The power quality improvement by using DSTATCOM has been presented in this research. Analysis of the DSTATCOM model was done and it was developed in MATLAB/Simulink with power system block toolbox. Here, its control system is designed in MATLAB Simulink. Therefore, DSTATCOM provides fast acting dynamic reactive compensation for voltage support during voltage flicker events.

Here the number of switches required are less and hence the switching losses are also reduced. The size and cost of the device are less and hence PWM switched auto transformer is an efficient and economical solution for voltage sag mitigation.

This research on power quality problem mitigation using D-STATCOM and fault detection using S-Transform significantly advances the current understanding and capabilities in power system management. D-STATCOM offer dynamic voltage regulation, harmonic mitigation, power factor correction, and improved transient stability, leading to enhanced power quality and economic benefits. Meanwhile, the application of S-Transform for fault detection introduces a highly accurate, real-time, and reliable method for identifying and localizing three-phase faults, contributing to the robustness and reliability

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